

Seismic Stimulation of Oil Production in Depleted Reservoirs

(supported by Advanced Energy Projects Division of DOE/OBES)

Project Status
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Overview

Our efforts in the first year of this project have been focused largely on startup tasks. These include design and construction of a new and unique laboratory facility, staffing of the LANL technical team, garnering additional industry interest and support, and laying the groundwork in the project's 4 major research focus areas (see below). Currently, design and procurements for the laboratory are completed and the facility should be assembled and functional in January, 1997. Industry collaboration has grown, and now 12 companies are participating, including major producers, service providers, acoustic technology vendors, and oil and gas consulting firms.

Company names and contacts can be found listed on the project's world-wide-web site. The location of this site is shown above. This status report can also be downloaded from the web site. The web site will serve as the primary means of communicating project information and results to all participants. Those of you who do not have internet access will continue to receive updates via normal mail, but we strongly urge everyone to get connected to the network. In addition to the website, we have created a bulletin board mailing list for the project. This is simply a distribution list that anyone can post messages to via email. Anyone who has subscribed to the list will receive these postings. It is an efficient means of communicating project news to all participants, including news about new results that have been recently installed on the website. This is another reason we strongly urge everyone to get themselves set up on the internet with an email address. To subscribe to the mailing list, send a single line email message to <listmanager@lanl.gov>, with nothing in the subject header. The message should read exactly as follows, with your email address placed where indicated (you don't have to type the < > symbols):

subscribe reservoir-stimulation <your email address>

Once you are subscribed, you will receive confirmation via email. You can post messages to the list by emailing to <reservoir-stimulation@lanl.gov>. Everyone who has subscribed will receive your posting. Please contact Peter Roberts if you have any problems.

The first project general meeting was held in March, 1996. Representatives from five of our industry collaborators attended. Short and long term research goals were clarified based on industry priorities and potential for advancing our scientific understanding of acoustic enhancement of fluid flow in porous media. This report is intended as an update on progress made and current status of the project in the following 4 major focus areas:

- 1.) Experimental laboratory investigations
- 2.) Theoretical modeling of the effects of sound on fluid percolation
- 3.) Compilation of field production data
- 4.) Planning of field stimulation tests

Summary of Status in 4 Major Areas

1.) Laboratory

a.) Permeability Enhancement Apparatus

Laboratory apparatus is currently being assembled to study the effects of low frequency stress waves on the permeability of rock core samples. The main component of the system is a triaxial core holder, capable of applying up to 10,000 psi axial and radial confining pressure to the core samples. It is designed to hold cores 1 inch in diameter and up to 24 inches long, and will accommodate single-phase and two-phase flow at static fluid back-pressures up to approximately 9,000 psi. With additional parts, cores as large as 3 inches in diameter can be tested. Constant-flow-rate pumps will be used to produce pulse-free flow of oil and water mixtures through the cores. Currently, accurate flow rates of 0.02 to 800 cc/min can be achieved. Absolute and relative permeabilities will be measured using differential pressure gauges positioned at selected lengths along the core. Stress cycling at frequencies from DC to approximately 2000 Hz will be generated by direct mechanical coupling of the core to a Terfenol-D magnetostrictive actuator attached to one end of the core holder apparatus. The actuator can deliver dynamic force as high as ± 200 lbf P-P with a maximum displacement of ± 0.002 " P-P. Thus, we can create Young's mode strains as high as approximately 10^{-4} in a 1-inch-diameter sandstone core. We also have obtained a manufacturer's design for an actuator that can deliver up to ± 1000 lbf P-P with a displacement of ± 0.001 " P-P. A load cell in series with the actuator and core will provide calibrated measurements of applied stress and one or more strain gauges attached to the side of the core will allow dynamic measurements of Young's modulus to be made during acoustic stimulation of the sample. Experiments will be conducted using a range of differing formation rock types as well as composite samples with varying initial permeability versus axial position.

The theory of operation for this apparatus falls in the domain of so-called lumped element dynamics. If the wavelength of acoustic excitation is much longer than the largest dimension of the sample, the entire rock/core-holder system can be modeled as a combination of masses and springs. In this case the core can be viewed as an infinitesimal element of host rock from an oil reservoir and the effects of Young's mode acoustic stimulation should be analogous to the effects on sub-elements of a reservoir as seismic pressure waves pass through it. In addition to this mechanical squeezing mode of stimulation, the core holder has been designed to allow non-deformational shaking of the core to study inertial effects, as well as direct fluid pressure pulsation under static mechanical load to study relative pore pressure effects. We anticipate these 3 modes of stimulation will be useful for assessing various technological approaches to downhole and surface acoustic field stimulation that are currently being pursued by the oil and gas industry.

A schematic diagram of the laboratory core flow apparatus, configured for single-phase (oil or water alone) flow, is included here and can also be found on the project web site (see above). An additional constant-flow pump will provide the second phase flow (oil plus water) and mixing will occur at the core face. The core holder has a total of 12 pressure taps along the 24-inch-long sample confinement sleeve (only 3 taps are shown in the diagram). This will allow monitoring of permeability changes over individual sections of composite-permeability samples. The entire apparatus will be computer controlled through bus interfaces to the various instruments, gauges and pumps. Using National Instruments' LabVIEW software, an entire suite of experiments can be carried out automatically and unattended. This will allow testing a large number of initial conditions and stimulation parameters in a relatively short period of time. A diagram showing some of the core flow experiments we intend to perform in 1997 is attached.

Although this apparatus is designed primarily to produce empirical data that will provide direct guidance for larger scale laboratory and field testing, additional measurement devices in the core holder may help us identify one or more of the possible physical mechanisms of enhanced fluid flow. Some of the mechanisms proposed by other researchers and theoreticians invoke phenomena that can only occur at the pore scale, and, thus, require high frequency waves. It has been suggested that low frequency energy can be converted to higher frequencies through mechanical interactions with the grains and fluids in the saturated porous material. If so, we should be able to detect these higher frequencies using the strain gauges on the rock or hydrophones coupled to the pore fluid.

b.) Optical Visualization Apparatus

Several experiments, independent of the core flow testing above, are being designed to study some of the possible physical mechanisms for enhanced fluid flow. These will be performed mostly at high frequencies to investigate the importance of pore-scale interactions. An optical cell has been designed that will allow direct visualization of fluid behavior in artificial porous media using a microscope. The cell will be packed with glass beads that are optically matched with the saturating fluid. Acoustic source probes can be inserted into the cell and relative fluid motion can be observed during acoustic stimulation of the sample. Two of the mechanisms we can look at with this apparatus are coalescence of trapped oil ganglia and fluid boundary layer disruption. We can also produce low frequency excitation of the cell, either by vibrating the cell itself or by oscillating the fluid pressure during static flow.

2.) Theoretical Modeling

Theoretical modeling must begin with the classic set of equations that govern the dynamics of fluids in porous media. This is a well-developed field (Bear, 1972, 1991). The theoretical model must include equations of motion for two-phase flow, continuity conditions, and state (stress-strain relationship). Thermodynamic equations describing heat transfer may also be necessary. Classic theories describing elastic wave propagation in porous media have already been developed (Biot, 1956a, 1956b). It may be necessary to use a combination of Biot theory and the aforementioned set of transport equations to fully determine the model.

Our work is aimed at clarifying general mechanisms responsible for accelerated percolation of fluids and enhanced gravitational segregation of oil and water that are observed in porous media under the influence of elastic waves (Beresnev and Johnson, 1994). The possible known mechanisms include interaction of sound with liquid films adsorbed on pore walls, sound effects on capillary forces, and the effects of alternating pressure on fluid dynamics. However, there is a fundamental lack of quantitative understanding of the relative importance of these and other effects.

A limited theoretical investigation into the mechanisms of elastic-wave enhancement of fluid transport in porous media has been done in Russia (Kuznetsov and Simkin, 1990). We are conducting a full-scale study of these phenomena by solving the corresponding equations numerically and presenting the results in a form convenient for direct laboratory verification using the core-flow apparatus described above. The eventual goal is to determine the most effective mechanisms for enhancing flow in the field and to identify promising technologies for triggering these mechanisms using either downhole or surface sources.

3.) Historical Field Production Data

Several new sets of historical production data have been obtained, and we are currently assembling these data in a form convenient for analyzing statistical correlations between production rates and well-documented sources of vibration. In addition, a detailed report on the results of a recent field test performed by one of our industry collaborators has been obtained. This test involved the use of the so-called hydroimpact technology, which generates high pressure fluid pulses in the wellbore that propagate strong seismic waves laterally into the formation when the pulses impact the bottom of the well. The data from this test are still being analyzed, but it appears that oil production increased on about 50% of the individual wells that were monitored. This is typical of many previous field tests reported in the literature as well. We hope to improve this success rate through better understanding of the physical parameters and mechanisms, as well as through careful statistical analysis of existing production data.

The historic data we are currently compiling or making arrangements to obtain are:

- 1.) The THUMS field in Long Beach, California provides a unique opportunity to look for correlations between production rates and spatial-temporal proximity to earthquake hypocenters. We are currently compiling these data.

- 2.) The Teapot Dome field in Wyoming, now operated by DOE through the Rocky Mountain Oilfield Testing Center (RMOTC), has production data available for over 600 wells. RMOTC has agreed to help look for correlations between production and nearby sources of vibrations, such as drilling

operations, etc. They also report that a magnitude 4 earthquake occurred recently about 20 miles away from the producing field.

3.) MIT is providing production data for a producing field in Michigan, where they have been conducting numerous seismic surveys using surface Vibroseis sources since 1983. At first glance, it does not appear that these surveys have had any significant affect on oil production rates. These data could be important for narrowing in on the range of field conditions and formation properties that seismic stimulation is likely to work within.

4.) We have access to production data for several fields in the Bend Arch region of north central Texas. We are currently working with producers in the area on a separate project involving ultrasonic wellbore cleaning, so far with great success. They are interested in the reservoir stimulation application, and, although they have not formally joined the project yet, are willing to share their production data, which includes monthly and some daily production rates for several hundred wells over a period of about 10 to 20 years.

4.) Field Testing

Although this project will not actively pursue field testing until the third year of research, we have every intention of helping to coordinate, design and carry out any independent testing that our industry collaborators or others may conduct. Our initial efforts are strongly focused on the laboratory and theoretical work, but we expect our results will provide useful guidance for any field testing that may take place during 1997. There are currently about half a dozen or more proposed field technologies for stimulating oil reservoirs with seismic frequency waves, either from within a wellbore or from the surface. Each of these are represented by one or more industry participants in this project. These technologies can be roughly grouped under 3 major headings: 1.) seismic or acoustic sources coupled to the wellbore wall either mechanically or through the wellbore fluids, 2.) wellbore fluid or gas pressure pulsation devices, and 3.) surface vibrational sources coupled either to the wellhead or directly to the ground.

Most of our industry participants are eager to get field testing started as soon as possible. In particular, Texaco is trying to get a comprehensive test put together in the Humble field in Houston sometime early in 1997. The details and scheduling for this test are still being worked out, but the main idea is to test and compare as many different field technologies as possible, in a controlled experimental environment involving well-characterized producing wells and a nearby test well for applying the stimulation. We will keep all interested parties informed as the details of this test unfold.

In addition to the Texaco test, we are working on setting up a collaborative field test at RMOTC, which is an ideal real-world testing facility for this kind of research. RMOTC can obtain independent DOE funding to support a maximum of 50% of the field testing costs, and they are eager to participate in such a test. We are currently writing the field work proposal for this. Depending on how rapidly the lab work progresses, this test could conceivably be performed before the end of 1997. We will not proceed, however, until enough conclusive experimental lab data and theoretical predictions are obtained to allow for the appropriate selection of field conditions, sources of stimulation and treatment parameters.

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